Chapter 4

Geology and Hydrogeology

Chapter 4

Geology and Hydrogeology

4.1 Primary Issues

Protection of water resources at the site is a major project issue, since Vashon/Maury Island residents rely on groundwater for their water. With the Applicant proposing to remove large amounts of earth from the site, changes in the water regime of the site would be inevitable. This chapter evaluates primary issues associated with the geology and hydrogeology of the property, as identified by the EIS Team and by concerned citizens.

The primary issues analyzed are:

- Would mining as proposed affect recharge of the aquifer system or affect the availability of water to residents on Vashon/Maury Islands?
- Would mining affect groundwater quality?
- Would the mining activity breach an aquifer or otherwise impact adjacent groundwater wells being used by local residents?
- Would the proposed mining cause saltwater intrusion into the freshwater aquifer?
- Would the proposed mining activity create slope stability problems?
- Would proposed mining affect surface water resources?

4.2 Affected Environment

To understand how the proposed mining operation would change water regimes, one must first understand the existing geology and water regime. The following sections describe the water regime on the site and how it relates to the water regime on other lands within the Maury Island system.

A more detailed discussion and additional background information was given in Appendix A and Appendix E of the DEIS. Additional data on water quality and recent groundwater monitoring results are included in the FEIS as an Addendum to Appendix E.

4.2.1 Information Sources

This report documents King County's independent analysis and conclusions based on groundwater and geologic data from the site and surrounding area.

Information used for this analysis includes previously published and unpublished data and reports, as well as data gathered from the site by King County's EIS Team. Sources of data include:

- two 2-inch-diameter water wells (OBW-1 and OBW-2) installed on the site prior to the DEIS analysis;
- a soils, geology, groundwater, and geological hazards study prepared by Associated Earth Sciences, Inc. (AESI 1998, 1999);
- studies conducted for the Applicant by ESM (1998);
- two exploration soil borings (EB-3 and EB-4), also installed prior to the DEIS study;
- five new 6-inch diameter monitoring wells (OBW-5 through OBW-9) installed under the observation and guidance of the EIS Team as part of the DEIS, three of which are equipped with continuous-recording transducers that track *static water levels* (i.e., groundwater depth at a specific time and place);
- direct observations by the EIS Team of exploration pits dug on the site by AESI;
- well logs from similar geologic mapping and well drilling operations that have occurred throughout Maury Island, obtained from the Department of Ecology (Ecology, Central Files);
- Ecology's Water Rights Application Tracking System for Maury Island (Ecology 2000c);
- well logs from the Sandy Shores and Gold Beach wells obtained from the Washington State Health Department;

- the Vashon/Maury Island Water Resources Study (Carr and Associates 1983, referred to as the “Carr report”), a general study conducted for the entire Vashon/Maury Island area;

- the Vashon/Maury Island Groundwater Management Plan (Vashon-Maury Island Groundwater Advisory Committee 1998), which provides a framework for managing groundwater on Vashon/Maury Islands and outlines the overall geology and groundwater regimes of the islands;

- the United States Geological Survey (USGS) geologic map of Vashon and Maury Islands (Booth 1991);

- results from quarterly groundwater monitoring conducted at the proposed project site since preparation of the DEIS (included in the FEIS as an addendum to Appendix E); and

- results from the Department of Ecology Maury Island Gravel Mine Hydrogeologic Impact Assessment (Pacific Groundwater Group 2000).

Ecology’s Mid-Study Fact Sheet (Ecology 2000a) and Final Fact Sheet (2000b) provide brief, less technical summaries of the Ecology results and are included in the FEIS as Appendix I.

King County’s EIS Team determined that the five new wells were needed (1) to define the groundwater depth, changes in depth over time, and groundwater flow paths; and (2) to provide stations for long-term groundwater monitoring in the event the proposed mining were to proceed. The EIS Team provided input on where wells should be located; reviewed and concurred with selected well locations; observed well drilling and logging; and used the monitoring data to conduct the independent analysis and assess how mining would affect water regimes. Locations of the onsite and offsite water wells used in the analysis are shown in Figures 3 and 9 of Appendix A of the DEIS.

These wells will continue to track groundwater levels, thereby showing how groundwater levels change over time and/or during mining, and can be used to guide future mining activities, such as the final excavation limits to be specified in the Grading Permit.

The 6-inch diameter well holes range in depth from 60 to 300 feet below the existing surface. As they were drilled, geologists took samples of the materials and mapped and described them (AESI 1999). The EIS Team used these descriptions together with logs obtained from other geologic mapping and well drilling operations in the area to describe the geology of the site and neighboring areas. Well logs from throughout Maury Island have been recorded by many different geologists for many different purposes. Therefore the terminology varies and some interpretation by the EIS Team was required. The geologic cross-sections are based on those logs with the most consistent terminology, using the best judgment of the EIS Team based on local experience in the Puget Sound basin. Appendix A of the DEIS provides details regarding the AESI and other well reports.

The terms used in this EIS follow Carr and Associates (1983), Vashon-Maury Island Groundwater Advisory Committee (1998), Booth (1991), and Ritzi (1983). The Carr report provides general information for the vicinity but lacks site-specific information and details. Likewise, the Groundwater Management Plan provides a framework for managing groundwater on Vashon/Maury Islands and outlines the overall geology and groundwater regimes of the islands. The specific classifications of aquifers and related geologic features in these two reports are useful in discussing specific groundwater sources in the vicinity of the site. Differences between these sources were recorded through the use of site-specific subsurface data. Terms and conditions reported on the USGS geologic map (Booth 1991) were also used in this analysis. However, the USGS geologic map was a regional effort and variations exist between this regional mapping effort and the site-specific information collected for this EIS. The analysis presented in this chapter therefore is based largely on the site-specific information obtained by direct sampling at the site.

4.2.2 Geology

4.2.2.1 Site Topography

The general topography of the site is characterized by a surface sloping gently downward from the inland portion of the site, culminating in steep bluffs along the shoreward edge. These bluffs range from 200 to 300 feet above the Puget Sound shoreline. The bluff faces are covered by vegetation except in the immediate vicinity of the conveyer system and dock, and in places where the top layers of soil have slid off the slope, resulting in exposed soils (a process referred to as shallow sloughing). Such sloughing is a natural process that occurs on similar bluffs throughout the shorelines of Puget Sound. The toe of the bluff has been eroded by wave action. This erosion is a natural process.

Mining at the site has caused some obvious changes to site topography. At the eastern portion of the site, past mining removed up to 250 vertical feet of material, resulting in a large, horseshoe-shaped excavation covering about 40 acres. Other mining-related changes at the site include two unpaved roads that lead off of SW 260th Street along the northern margin of the site. One road enters the site near the northwestern corner of the property and provides access to the upland portion of the site. The second road enters the site near the northeastern corner and provides access to the low-lying part of the site, including the existing dock.

The materials that make up the geology of the site include topsoils and a discontinuous layer of till near the surface. This is underlain by coarse sands and gravels, grading to finer sands near the bottom of the deposit. These materials have been deposited over time at the site as a series of layers.

4.2.2.2 Surface Materials

Surface materials (or surface soils) are the upper and most weathered part of the soil profile. It follows that surface soils are the youngest materials on the site. These soils formed onsite by weathering and erosion of underlying materials and, therefore, reflect the composition of these deeper materials. The sandy and gravelly soils present onsite are part of the Everett series soils. Where glacial till occurs close to the surface, the soils are rocky and mixed, and are part of the Alderwood series soils.

4.2.2.3 Subsurface Materials

The site is underlain by glacial till, sand, and gravel. Till is a relatively unsorted mixture of clay, sand, gravel, and rocks (ranging in size from pebbles to boulders) left by glaciers.

The shallowest of these materials on the site is classified as Vashon lodgment till, and it occurs in thin pockets near the surface throughout the site. The Vashon till was deposited at the base of the Vashon age glacier that occupied the Puget Sound basin about 13,000 to 16,000 years ago. This soil was deposited beneath the moving ice. Till in the Puget Sound region is often thick (sometimes occurring in a layer 100 feet or deeper) and sometimes bound tightly like concrete. Because of this, till often has low permeability, meaning that water does not flow through it very easily. At this site, the top of the till layer is typically around 5 feet below existing grade. In addition, in its thinner occurrences, it lacks the concrete-like structure found elsewhere. The till has been documented to become thinner and discontinuous along the northern and western portions of the site. Therefore, the till at this site does not form a major barrier for subsurface water flow.

Underneath these thin pockets of till is a deep layer of sand and gravel referred to as Vashon Advance outwash deposits. These are the materials that would be mined. The Vashon Advance outwash sand and gravel were deposited by meltwater streams and rivers that flowed off of the glacial ice as it advanced into Puget Sound from Canada approximately 16,000 years ago. These materials grade from coarser sand and gravel near the top of the deposit to finer sands near the base.

The materials that would be mined continue from near the surface down to various depths. The differences in depth are typical in the Puget Sound region, because the materials were deposited over rolling hills and valleys rather than over a flat surface. The sands and gravels at the site appear to have been deposited in a historic basin situated between hills. The site is situated near the center of this basin, which allowed a thick sequence of sand and gravel to accumulate and form the deposits that are the basis for mining at the site.

The advance outwash soils that make up the majority of the materials on the site exhibit a range of permeabilities (a measure of how easily water flows down through a material). Overall, the materials are highly permeable (water flows easily through them), especially near the surface. This is because materials near the surface are coarse gravels and sands with abundant gaps that allow water to flow downward (i.e., they have higher permeability). Water flows less freely (i.e., slower) in the lower portions of the deposit, where finer materials are packed closer together, allowing less space for water to flow through.

While the materials that would be mined vary in permeability, none are so impervious as to form a water barrier or to slow water flow to the point that it forms an aquifer (such a barrier is called an aquitard). Small, isolated pockets of water-saturated materials are expected to occur due to differing material size and density, but none of these “pockets” would contain sufficient water to be considered an aquifer. The local pockets of perched water that may exist within the materials to be mined would be saturated for only short periods of the year and would not be a credible or dependable source of water for beneficial water uses, such as irrigation or domestic water supplies (see Section 4.2.4.3).

The oldest material encountered beneath the site is a series of fine sands with some silt beds. The stratigraphic correlation for these sands has not been determined. Carbon-14 dating of organic material from these lower sands showed that the sands are older than 45,000 years. Due to the amount of organic material present, these sands appear to be an interglacial deposit. The Olympia Beds, the common aquitard present on Maury Islands, were not specifically encountered during onsite exploration. The Olympia Beds are commonly believed to have an age on the order of 16,000 to 80,000 years before present. Mining would not extend into these older pre-Vashon sands, which lie below the materials that would be mined.

4.2.3 Surface Water

Besides the obvious presence of Puget Sound and the associated tidelands, no streams or other surface waters enter the site. Therefore, rainfall and groundwater are the only potential sources of surface water at the site.

Water exits the site via springs along the beach. These springs are below the area that would be mined. These springs exist where the top of the aquifer has been exposed by past wave erosion.

Because the site is underlain with highly permeable sand and gravel, rainfall that is not directly evaporated or transpired through site vegetation percolates down into the underlying groundwater system, rather than collecting in wetlands or streams. No evidence of creeks or seasonal water bodies is present on the uplands or within the pit area on the site. During heavy rains, water collects and runs off the compacted soils on existing roads, and drainage channels are present along the edges of roads. These storm flows follow the compacted drainage channels until reaching undisturbed areas or exposed sands of the existing pit area, where they then rapidly enter the ground.

4.2.4 Groundwater

4.2.4.1 Overview of Basic Terms and Concepts Related to Groundwater

Groundwater is any water present beneath the surface. It occurs in open spaces in soil, sand, gravel, and other sediments, and is a major element of the hydrologic cycle. The hydrologic cycle begins with precipitation (typically rain on this site), which infiltrates relatively quickly into the ground at the Glacier Northwest site.

Once water enters the ground, it will flow downward through porous and permeable materials, such as gravel and sand, until reaching an impermeable barrier (called an aquitard), such as a layer of compact till, thick clays, fine silts, or water pooled up behind such layers.

When a significant amount of water remains in place over time and completely saturates the subsurface materials, it is called an aquifer. For the purpose of this EIS, an aquifer is defined as "A formation, group of formations, or part of a formation that contains sufficient saturated permeable materials to yield economic quantities of water to wells or springs" (Driscoll 1986). An aquifer can occur at different depths or be otherwise dispersed throughout the three-dimensional area beneath the surface.

Based on the analysis conducted for this EIS, four main groundwater bodies have been identified in the vicinity of the site: (1) an interflow network, (2) perched water, (3) the principal aquifer, and (4) the deep aquifer. The following sections describe these groundwater bodies.

4.2.4.2 Interflow Groundwater

Interflow groundwater is the water below the ground surface that is not part of an aquifer. In the Puget Sound basin, interflow typically develops near the surface within low-permeability soils. Often, this lower permeability layer is a till. The interflow typically moves laterally (sideways) along the top of the till rather than vertically (downward) through the till. Interflow recharges streams and creeks in the Puget Sound basin. The interflow also serves as a reservoir for deeper recharge through the till or other material that comprises the upper aquitard.

Based on direct field observations made by the EIS Team, and on the Team's analysis of data collected by AESI, no significant interflow network exists on the site. In other words, water is not entering the ground and then flowing laterally (sideways) off the site. Instead, the rainfall that is not directly evaporated or taken up by vegetation continues to move downward to recharge the aquifer below the site's surface.

The only exception is that laterally flowing water was detected above the till layer that occurs near the surface at one location. As mentioned earlier, these till areas are relatively less permeable than the underlying sands and gravels, but, nonetheless, do allow water to flow through them. In addition, since the till layer occurs in patches, the laterally flowing water eventually reaches more permeable sand and gravel, at which point it starts to move downward toward the water table to recharge the principal aquifer.

The interflow that has been mapped on the site would not be a credible or dependable source of water for beneficial uses such as irrigation or drinking water. This is due to the seasonal nature of the interflow and its limited extent. At the height of the irrigation season, the interflow would be absent. The measurements that have been done onsite indicate that the interflow is present in limited areas and only during the wettest winter months.

4.2.4.3 Deeper Perched Water

At some places on the site, layers of more densely packed sands and gravels slow the downward movements of water to the point that isolated "pockets" of water form. Such pockets were found at two of the wells on the site. The depths of these pockets were 45 feet (well OBW-6) and 200 feet (well OBW-7). Because these layers of more dense materials are not connected, the pockets of water are also not connected. Thus, water eventually either drains slowly through these materials or flows off the edges of the deposit where sand and gravel occur, and then percolates downward to recharge the aquifer. This is similar to the situation previously described within the till layer, where, in places, water is slowed and may move laterally, only to eventually drain through discontinuities in the material or by reaching the permeable sands and gravels.

4.2.4.4 Aquifers

An aquifer is a relatively large and stable underground water body formed by water-saturated materials above some sort of impermeable barrier. In previous studies conducted on Vashon/Maury Island, researchers described a principal aquifer, which resides in the sands and gravels of the Vashon advance outwash, and a deep aquifer, which resides in the much lower, pre-Vashon sediments. This is the typical system that occurs throughout the Puget Sound region, since the Vashon outwash deposits typically are underlain by silts and clays that restrict water flow. This base serves to separate groundwater into distinct aquifers.

At the project site, however, it appears that this separation between the principal aquifer and the deep aquifer is not so distinct. The silts and clays are absent beneath the Glacier Northwest site and vicinity. For the purposes of EIS analysis, the aquifer at the site has been considered one continuous system. Other pre-Vashon aquitards do exist in the vicinity of the site, where the deep aquifer is clearly separated from the principal aquifer. This assumed hydraulic continuity between the principal and deep aquifer is a conservative assumption. Were such an aquitard present, then any change in recharge at the site would have little effect on the deep aquifer. Were a significant clay or silt lacustrine deposit present beneath the advance sands, this aquitard would significantly reduce the ability of groundwater from the advance sands, the principal aquifer, to flow towards the deep aquifer present in pockets within the pre-Vashon sediments. With no significant aquitard, as shown by the existing exploration data, the deep aquifer is more susceptible to impacts from decreased recharge to the principal aquifer. Hence, the assumption that there is no significant aquitard is a conservative assumption.

At the Glacier Northwest site, the materials that would be mined are located above the primary aquifer.

4.2.4.5 Static Water Levels

For mining, one of the most important considerations is at what depth is the top of the aquifer located? This elevation is often referred to as the water table, and measurement of the water table taken from wells is called the static water level.

Static water levels are not fixed, but rather change in response to weather patterns and, sometimes, human influences. Human influences can be removal of large amounts of water through wells, or changes in the recharge regime by intercepting rainwater and diverting it away from the aquifer recharge zones.

Even with these variations, the overall water level measured at any one particular point on the site is relatively stable. Water that enters these sands and gravels travels downward slowly. At the Glacier Northwest site, it is expected that rainwater takes up to 6 months to percolate down through the sands and gravels until finally reaching the water table. The existing data suggest that the time lag is 6 months for the higher portions of the site and 1 to 2 months for the existing mine area where significant materials have already been removed. Water moves downward until it reaches the water table and enters the aquifer. In addition, the site is situated in a sand-filled bowl where water that has infiltrated elsewhere offsite is directed towards the site by the sloping surface of the lower permeability pre-Vashon sediments. Therefore, despite variable precipitation such as rainstorms at the surface, the water table at the site is expected to fluctuate on the order of only a few feet over the course of a year. Ongoing monitoring would provide more information regarding this natural fluctuation and these data would be used for mine design should the project be approved.

Based on the wells established for this EIS and on previous wells, static water levels at the site measure between approximately 90 feet above sea level at the highest point to around 20 feet above sea level at the lowest. The levels generally follow the topography, with the higher levels located upslope and inland, closer to the primary recharge zones, and the lower levels located near the shoreline at the groundwater discharge area. Figures 4-1 through 4-4 map the groundwater table found at the site.

4.2.4.6 Aquifer Recharge

Water that enters the site (and that does not leave via evaporation or by being taken up by plants) eventually reaches the underlying aquifer, thereby contributing to recharge of the aquifer. The recharge occurs initially within the Vashon outwash sediments. From these sediments, some of the water continues deeper into the pre-Vashon sediments (referred to as the "deep aquifer" by Carr and Associates [1983]), while the remaining water flows directly from the outwash deposits to Puget Sound.

Looking at the site within the context of Maury Island, recharge generally occurs in a radial pattern centered on the highest and central-most portions of the island, with all discharge eventually going into Puget Sound (except for that removed via wells). The interface area, where the aquifer discharges into Puget Sound, is expected to occur underground along the margins of the island. This is a typical recharge regime for an island.

This "radial discharge" pattern is illustrated on the project site by the gradient of the water table, with the static water level being near 90 feet above sea level toward the upland portion of the site, grading down to near 20 feet at the shoreline area of the site. The water table at the site grades down to meet the waters of Puget Sound. Results from the Ecology study (Pacific Groundwater Group 2000) show that the site is located within a bowl consisting of lower permeability pre-Vashon soils that rise both north and south of the site. This is consistent with the County analysis. The principal aquifer flows down the flanks of these subsurface features towards the site. This is shown on Figure 4-5, taken from the Ecology Mid-Study Fact Sheet (Ecology 2000a; Appendix I). The springs on the shoreline below the site further indicate that this site has a discharge point for groundwater.

The speed of discharge from the freshwater aquifer to Puget Sound is greatly affected by the materials through which groundwater flows and the gradient of the top of the water table. Groundwater may flow relatively rapidly in some areas, more slowly in others. The project site is a point of relatively rapid discharge, due to the relatively deep deposit of highly permeable sand and gravel and its location in a subsurface basin.

4.2.4.7 Adjacent Wells and Springs

Numerous wells are located on Maury Island. Well and spring water is the only natural source of water on the island. The four major well systems addressed in this EIS are (1) the Gold Beach wells, (2) the Sandy Shores well, (3) the Iliad well, and (4) the Dockton Water Company (three sources).

These water supply systems are discussed explicitly since they represent typical water supply systems constructed in the vicinity of the site. Other systems with similar construction may exist. While these other systems are not discussed explicitly, the conditions described here are believed to represent the conditions that would exist at other offsite water sources based on the geologic conditions documented in King County's analysis.

The Iliad well is located about 0.5 mile northwest of the Glacier Northwest site. The Iliad Well is considered to have its inlet in the deep aquifer. The static water level given on the well log of the Iliad well puts the static water levels below sea level. This is unlikely to be correct. The static water level is expected to be at an elevation close to the levels of groundwater present beneath the Glacier Northwest site. Due to the assumed hydraulic conductivity between the Principal and Deep Aquifer beneath the site, some water from beneath the Glacier Northwest site may contribute to recharge of the Iliad Well.

At Gold Beach, which maintains two wells located side by side, the static water level is approximately 29 feet above sea level, which again corresponds to groundwater levels at the Glacier Northwest site at a similar distance inland. Thus, the Gold Beach wells are cross-gradient from the Glacier Northwest site. The Gold Beach wells are considered to tap the Principal Aquifer.

The Dockton Water Company obtains water from two springs and the Sandy Shores well. At the Sandy Shores well, the static water level is reported to be near 61 feet above sea level. Given its location, it is cross-gradient, or roughly at the same level, as the water table at the Glacier Northwest site. The sandy shores well is considered to have its inlet in the deep aquifer.

The first set of springs is in the center of a swale across the street from the Dockton Park. The water level in these springs is estimated to be about 30 feet above sea level. This corresponds with the elevation of the static water level at a similar position inland at the Glacier Northwest site. Because the water table is higher at places between the Glacier Northwest site and the Dockton Park springs, a groundwater divide separates the Dockton Park springs from the Glacier Northwest site. The divide is located somewhere south of the Glacier Northwest site as shown on Figure 4-5. This further illustrates the radial flow of water out from the center of the island.

The second spring field used by the Dockton Water Company is the Hake Springs. These springs are located at an elevation of about 100 feet above sea level. This elevation is higher than the elevation of the water on the Glacier Northwest site. Hence, Hake Springs is clearly upgradient of the Glacier Northwest site, meaning that water at the Glacier Northwest site does not flow to Hake Springs.

Groundwater flowing beneath the site has been determined to discharge directly into Puget Sound. Thus the portion of the site along the beach appears to be a discharge zone for water from the principal aquifer on this part of Maury Island. Some of the water beneath the site likely contributes to deeper aquifers in the immediate vicinity of the site.

Although no wells or springs are clearly downgradient of the site, the groundwater beneath the site is recognized as an important resource and part of the aquifers that provide groundwater to the citizens of Maury Island.

4.3 Impacts

4.3.1 Would mining as proposed affect recharge of the aquifer system or affect the availability of water to residents on Vashon/Maury Islands?

4.3.1.1 Proposed Action

Aquifer Recharge. A primary concern regarding the Proposed Action is that mining would limit aquifer recharge and decrease the amount of drinking water available to residents on Maury Island. The proposed project would alter the timing and path of aquifer recharge at the proposed project site, but overall, with mitigation measures outlined in Section 4.4, would have no adverse impact on water resources.

Overview. With appropriate drainage and recharge design (as described in Section 4.4), mining would not reduce the amount of water that this site currently contributes to the aquifer and, therefore, would have no adverse effect on local water supplies.

Previous and ongoing studies indicate that adverse impacts on drinking water would not occur for four main reasons. First, as stated earlier, the site does not contribute to a lateral interflow network that directs water offsite.

Second, as shown on Figure 4-5, groundwater flow from beneath the site is not directed towards any of the existing beneficial water uses, except for the Water Rights Claim held by Glacier Northwest. This is reflected in the downward "slope" of the groundwater found at the site, with depths being near 90 feet above sea level toward the top of the site, grading down to the shoreline area of the site. This reflects the typical offshore flow of groundwater on an island system.

Third, although mining at the site would change the timing and the path that rainwater takes from the surface of the site to the underlying aquifer, effects on the groundwater table would be localized and would not affect the amount of water available to residents. The timing of recharge would change through a major decrease in the time it takes rainwater falling on the site to reach the aquifer (see below under heading "Altered recharge regime").

Fourth, the amount of rainwater that enters the ground would actually increase at locations being actively mined and reclaimed.

This is because vegetation, particularly forest, intercepts much of the rainwater. In cleared areas, up to 10 times as much rainwater may enter the ground to recharge underlying aquifers compared to a forested area. This effect would occur within the 32-acre active mining cells and recently reclaimed areas. Eventually, vegetation on reclaimed areas would again take up much of the rainwater, thereby making this increased recharge a temporary effect that would occur only during and immediately following active operation of the mine. However, the final mine reclamation plan would not include total reforestation. Hence, some increased recharge would continue to exist due to roads, other impermeable surfaces, and pasture-like areas.

In conclusion, mining would not affect the local drinking water supply because (1) appropriate drainage and recharge designs would be used (Section 4.4), (2) the site does not contribute to lateral interflow, (3) the site is not located upgradient of existing beneficial water uses, (4) the amount of water reaching the aquifer would not be reduced, and (5) during operation and early periods of reclamation, recharge would actually increase because of vegetation removal.

Altered Recharge Regime. Removal of surface material by mining would change the timing and the path that rainwater takes from the surface of the site to the underlying aquifer, but effects on the groundwater table would be localized and would not affect the amount of water available to residents. The timing of recharge would change through a major decrease in the time it takes rainwater falling on the site to reach the aquifer. Water now takes up to 6 months to percolate through the deepest deposits of sand and gravel at the site. As mining reduces the depth of these deposits, this lag time would be reduced.

The magnitude of this reduction in lag time would depend on the depth of material left between the surface and the groundwater. This depth would be similar to existing depths near the site perimeter, but would become shallower toward the central portions of the mine, where, at final grade, a minimum 15 feet of surface material would separate the floor of the mine and the water table. At these minimum depths, water may take as little as 20 days to move from the surface to the underlying aquifer. At other locations, such as near the site perimeter, a greater depth would be maintained and recharge rates would be more similar to the existing conditions.

This decrease in recharge time would cause variations in the quantity of water entering the aquifer at any given time. This is because the existing deep sands and gravels act to “measure” the downward flow of water into a relatively stable flow as it reaches the groundwater table. With the depth of sands and gravels reduced, this measuring effect would be reduced. During rainy periods, recharge would be relatively high, and during dry periods, recharge would be relatively slow.

The water table is expected to respond to this variation by showing localized increases and decreases in the water table immediately below the site. The magnitude of such swings is estimated to be in the range of a few feet. Currently, the groundwater table varies, on average, about 2 feet. Following mining, localized variations up to about 5 feet may occur. Groundwater mounding could occur immediately beneath recharge facilities, with local mounds having a height of 10 to 20 feet above the surrounding static water levels. Because of this, the final elevations of the mine floor must be adjusted to accommodate potential maximum groundwater levels.

These variations would be localized at the site and would not affect the amount of water available to residents. This is because the amount of water entering the groundwater table would not change. Locally, a steeper groundwater gradient would occur. The gradient would increase in the immediate vicinity of infiltration facilities that would be created as part of the mine operation. The steeper gradient would flatten out through time and over distance. Moreover, the local groundwater mounding would dissipate radially, and not unidirectionally toward the coastline

The single recharge facility proposed along the eastern edge of the site would create increased groundwater flow velocities along the edge of Puget Sound, and groundwater would therefore be lost to Puget Sound at an increased rate. This would result in a lowering of the groundwater table towards the west and could eventually cause the groundwater divide between Dockton Springs and the proposed site to shift to the east, thereby decreasing flows of water to Dockton Springs.

Results of Ecology Study. The Washington State Department of Ecology has published its hydrogeologic impacts assessment for the Maury Island gravel mine (Pacific Groundwater Group 2000). The study included development of a numerical simulation model for groundwater flow, and simulation of mining and reclamation impacts on that flow.

Overall results from Ecology’s hydrogeologic impact assessment are largely consistent with the results discussed above, with a temporary increase in recharge and groundwater elevations during the early stages of mine development, and a small decrease in recharge compared to current conditions over the long term due to revegetation. A similar increase in vegetative cover would be likely under the No-Action Alternative, and would result in a similar decrease in recharge and water table elevation relative to current conditions.

The results of the Ecology Study indicate that, in the worst-case scenario, there could be a decrease of flow at Dockton Springs of 2 percent and a decrease of the average annual static water level on the site on the order of 0.6 feet compared to current conditions. These impacts too are related to revegetation, and would be essentially the same under the No-Action Alternative.

Surface Discharge. The proposed stormwater management ponds in the floor of the mine would be designed to contain runoff from up to a 25-year storm. This would allow surface runoff from the ponds to drain directly into Puget Sound during storms with intensity greater than the 25-year event, thereby decreasing the amount of water available for recharge to the aquifer. Over time, net recharge would decrease through the spilling of peak stormwater flows. Under existing conditions, there is no significant surface discharge of rainfall runoff to the Sound.

In summary, although the site is not presently in a position to directly recharge offsite beneficial water uses, uncontrolled and unmitigated development could eventually affect offsite water sources. However, by adopting the mitigation measures outlined in Section 4.4, these impacts would be avoided, and the project would have no adverse impacts on water resources.

Water Use. To control dust, the operator may use up to 10,000 gallons of water per day during dry periods. No other substantial water use would be expected at the site.

The daily water use on Vashon and Maury Island is currently about 1,200,000 gallons per day (Vashon-Maury Island Groundwater Advisory Committee 1998). Therefore, at maximum use, the site would increase daily water consumption on the Island by 0.8 percent.

Water for dust control would be used only during dry weather. Hence, the average daily water use over the course of a year would be less than the daily maximum use.

The Applicant did not specify a source for dust-control water. Given the sensitivity of water resources on Maury Island, it may be difficult or impossible to obtain water from on-island suppliers. Therefore, it is most likely that water would be brought to the site from off-island sources. This water would be applied to surface materials at the site, and would either infiltrate into the soil or evaporate. The amount of water that did not evaporate would infiltrate and would therefore increase total recharge to the aquifer.

Alternatively, Glacier Northwest could exercise its existing onsite water right claim. The water right claim allows the withdrawal of 8,000 gallons of water per day. A storage tank could be built on the site to store water to allow the maximum amount of 10,000 gallons per day to be available for dry periods. There would be no impact to the overall hydraulic budget at offsite existing water sources because the water withdrawn would be taken from along the eastern margin of the site where the immediate fate of groundwater flow is discharge into Puget Sound.

Other potential sources of water for dust control are municipal water systems either on the islands or from the mainland

In any case, conservation measures to reduce water consumption, as well as measures to vary the source of water, would serve to effectively reduce any strain on water resources.

4.3.1.2 Alternative 1

The impact of Alternative 1 is the same as the Proposed Action, with no decrease in available water to Maury Island residents. The effect of increased recharge through vegetation removal would occur over a longer period because the site would remain open for a longer period, thereby leaving exposed areas of rapid infiltration available over a longer time.

Potentially less water would be used under Alternative 1 for dust control.

4.3.1.3 Alternative 2

Same as the Proposed Action and Alternative 1, with no significant effect on the amount of drinking water available on the Island. As with Alternative 1, potentially less water would be required for dust control.

4.3.1.4 No-Action

The No-Action Alternative would not affect available drinking water for the same reasons stated under the Proposed Action. Dust control water needs would be negligible.

As under the Proposed Action, most of the site would eventually be revegetated, and a slight decrease in aquifer recharge and groundwater elevations relative to current conditions would be expected.

4.3.2 Would mining affect groundwater quality?

4.3.2.1 Proposed Action

The project would not significantly affect groundwater quality.

The primary concern related to groundwater quality is potential introduction of sediments or contaminants into the groundwater table. Concerns regarding arsenic and other contaminants related to the ASARCO smelter are addressed in Chapter 10.

The potential for impacts from fuel spills is small due to the relatively small amount of machinery that would be required to operate the mine. At full operation, up to three loaders and four bulldozers would be in operation. The Applicant has not specified fueling procedures, but typically a fuel truck supplies fuel at a designated location. As a good management practice, such designated fueling areas are lined to contain possible fuel spills. Such a measure has been included for consideration in Section 4.4.3.8.

Impacts resulting from sedimentation are not expected for several reasons. First, the sands and gravels at the site that separate the groundwater table from the surface would serve to effectively filter sediments or other contaminants. The sands that are present at the base of the proposed mining operation generally meet the specification for water treatment sands for stormwater management facilities (King County 1998). King County requires a minimum of 2 feet of such sands to filter stormwater. At the site, at least 15 feet of materials would be present to serve as a filter to groundwater. This would protect the aquifer from contaminants adsorbed onto sediment particles. No source for contaminants that would be dissolved in stormwater is expected during the mining operation.

Finally, as stated earlier, the site, with the exception of the Glacier Northwest Water Right Claim, is not located upgradient of any existing beneficial water uses, so that the trend of water movement is toward Puget Sound and away from any well sites and springs used for beneficial purposes.

4.3.2.2 Alternatives 1 and 2

As with the Proposed Action, Alternatives 1 and 2 would result in no significant adverse impacts on groundwater quality.

4.3.2.3 No-Action

Same as Proposed Action, with no significant adverse impacts on groundwater quality.

4.3.3 Would the mining activity breach an aquifer or otherwise impact adjacent groundwater wells being used by local residents?

4.3.3.1 Proposed Action

A major issue that must be addressed with any mining operation is the potential for breaching an aquifer. Breaching occurs when excavations cut into an aquifer, causing water to flow out.

At the Glacier Northwest site, the materials that would be mined are located above the aquifer. As described in Section 4.4, a 15-foot separation would be maintained between the bottom of the mine floor and the groundwater table. Therefore, there is no potential to breach an aquifer. As mentioned in Section 4.2.4.3, small, isolated pockets of water are expected to occur within the material that would be mined. However, these isolated pockets do not contain sufficient water to be considered an aquifer in themselves. The local pockets of water and the interflow do not represent credible sources of water for beneficial water uses.

4.3.3.2 Alternatives 1 and 2

No aquifers would be breached under Alternatives 1 and 2, for the same reasons identified under the Proposed Action.

4.3.3.3 No-Action

No aquifers would be breached under No-Action, for the same reasons identified under the Proposed Action.

4.3.4 New Section: Would the proposed mining cause saltwater intrusion to the fresh water aquifer?

This section has been added to address public concerns raised in comments to the DEIS.

4.3.4.1 Proposed Action

Saltwater intrusion occurs where groundwater levels are lowered, allowing saltwater to migrate into areas formerly occupied by fresh water. The classic hydrogeology of an island has a lens of fresh water that floats above the higher density salt water. On Maury Island, this situation has not been documented or expected to exist because sufficient water is available to recharge the existing aquifers. The flow of fresh water radially out from the center of the island appears to keep the saltwater/fresh water interface along the shoreline. Hence the simple mathematical relationship does not strictly apply to the Glacier Northwest site. However, a decrease in the amount of water present could result in a migration of the freshwater/saltwater interface towards the land and conceivably to beneath the land surface.

The existing mine, through removal of the forest cover, has increased the amount of water that recharges the principal aquifer beneath the site. Hence, it is safe to conclude that the existing mine has pushed the saltwater/fresh water interface towards the Sound.

During mining under the Proposed Action, increased recharge to the aquifer would continue to maintain the relative position of the saltwater/freshwater interface. Following mining operation, when recharge conditions are reduced to near but still above natural conditions, the salt/fresh water interface would return to its natural position.

4.3.4.2 Alternative 1

The impact of Alternative 1 is essentially the same as the Proposed Action, except spread out over a longer period of time.

4.3.4.3 Alternative 2

The impact of Alternative 2 is essentially the same as the Proposed Action, except spread out over a longer period of time.

4.3.4.4 No-Action

The impact of the No-Action Alternative would be the same as the existing conditions and no significant net change in the existing saltwater/freshwater interface would be likely.

4.3.5 <u>New Section</u>: Would the proposed mining activity create slope stability problems?

This section has been added to address public concerns raised in comments to the DEIS.

4.3.5.1 Proposed Action

The existing bluff along the eastern margin of the site has several shallow seated sloughs that have occurred. These sloughing events are a result of wave erosion at the toe of the slope. This erosion at the toe of the slope creates a steeper sea bluff and initiates soils movement through shallow sloughing. This is a natural process that will continue with or without mining unless a bulkhead or other erosion barrier is constructed along the toe of the bluff. The Proposed Action does not include any erosion protection along the beach.

The Proposed Action would result in locally unstable slopes within the mine during active mining. However, these slopes would be part of the active working face of the mine and they would be trimmed to a final slope inclination of approximately 2:1 horizontal to vertical during site reclamation. The Proposed Action would also decease the overall height of the sea bluff along the eastern margin of the site. This would decrease the amount of material that would slough during future erosion events along the sea bluff.

Removal of the upper portion of the bluffs through mining would increase overall slope stability by (1) removing portions of the bluff and (2) eliminating the seasonal seepage that could occur along the contact of the looser surficial soils and the underlying till that is present along the top of the bluff. However, local sloughing would continue to occur as a result of wave erosion along the toe of the sea bluff. This wave erosion is a natural process that has been occurring since formation of the existing Puget Sound following the retreat of the glaciers.

4.3.5.2 Alternative 1

The impact of Alternative 1 is essentially the same as the Proposed Action.

4.3.5.3 Alternative 2

The impact of Alternative 2 is essentially the same as the Proposed Action.

4.3.5.4 No-Action

The impact of the No-Action Alternative would be the same as the existing conditions and no significant net change in the existing bluff stability would be likely.

4.3.6 New Section: Would proposed mining cause surface water runoff to flow off the site?

This section has been added to address public concerns raised in comments to the DEIS.

4.3.6.1 Proposed Action

As discussed in Section 4.2.3, no surface water enters the site, and thus there will be no impact on streams or other surface waters originating offsite.

Rainfall and groundwater are the only potential sources of surface water at the site. Due to the porous nature of surface soils at the site, rainfall that is not intercepted by vegetation, directly evaporated, or transpired through site vegetation percolates into the groundwater system. No substantial ponding or surface accumulation collects onsite, as confirmed by Ecology (2000a). Thus there will be no impact to surface water collected onsite.

Introduction of additional compacted soil surfaces, such as roadways, during mining could produce localized surface water accumulations. Any such accumulation would flow along roadside drainages to areas of undisturbed soil, where it would rapidly infiltrate. Therefore, no offsite runoff would occur, and the availability of water for aquifer recharge would not be affected.

Groundwater at the site discharges from springs located near the tide line, and downslope from any proposed mining activity. Because no mining would occur at this location, there would be no impact on these tide-level springs. Recent testing of groundwater quality of these springs (Ecology 2000a) shows that water quality meets Washington state water-quality standards for Class AA surface waters. No evidence of leaching of arsenic, cadmium, lead, or other contaminants was detected in spring water, and Ecology (2000a,b) concluded that the proposed containment plan would further reduce the possibility for contaminant leaching (see Chapter 10).

The proposed storm water management ponds would be designed to contain runoff from up to a 25-year storm event. This would allow runoff from the ponds to drain directly into Puget Sound during storms with an intensity greater than the 25-year event, thereby decreasing the amount of water available for recharge to the aquifer (see Section 4.3.1).

4.3.6.2 Alternative 1

The impact of Alternative 1 would be the same as under the Proposed Action.

4.3.6.3 Alternative 2

The impact of Alternative 2 would be the same as the Proposed Action.

4.3.6.4 No-Action Alternative

The impact of the No-Action Alternative would be the same as existing conditions.

4.4 Adverse Impacts and Mitigation

4.4.1 Significance Criteria

King County considers the following as indicators of significance for geology and hydrogeology impacts under SEPA.

- Reducing aquifer recharge or availability of water to residential users on Vashon/Maury Island.
- Reducing groundwater quality below groundwater standards and/or drinking water standards, if such water is or could be used as drinking water.

- Reducing water available in local wells, either by aquifer breech or other factor.

- Exposing the groundwater table.

4.4.2 Measures Already Proposed by the Applicant or Required by Regulation

a. To prevent impacts from sedimentation, the walls of the mining pit would slope toward the mine floor and away from Puget Sound, thereby reducing runoff into the Sound.

b. A retention/infiltration pond would be constructed at the bottom of the mine site. This pond would be sized according to WDNR and King County standards for a 25-year, 24-hour storm event.

c. Additional sedimentation ponds would be constructed to reduce the chance that siltation would limit the infiltration capacity of the retention/infiltration pond.

d. To reduce sediment transport velocity and potential sedimentation impacts, rock check dams would be established at minimum intervals of 75 feet in benches or channelized runoff paths where gradients exceed 10 percent. Runoff paths would be directed into the retention/infiltration pond.

e. The site would be excavated to an elevation that would maintain a minimum 15-foot buffer between the bottom of the pit floor and the measured or predicted static groundwater level.

f. Although groundwater is not likely to seep into the mining area, action plans to respond to such seepages would be included in the mining plan. Such plans would include immediate notification of King County.

g. To prevent mining into the groundwater, the Applicant would establish monitoring wells, according to the terms outlined in a Groundwater Monitoring Plan required as part of the grading permit. Any natural fluctuation in the static level of the aquifer would be identified as mining progresses, and the depth of mining would be altered as necessary to maintain the 15-foot buffer.

h. Groundwater levels would be monitored on a quarterly basis over a 5-year period following approval of the revised Grading

Permit and Surface Mining Reclamation Permit. After 5 years, monitoring may be reduced to annual measurements if no impacts to water levels have been identified. Monitoring would cease during the reclamation phase.

4.4.3 Remaining Adverse Impacts and Additional Measures

4.4.3.1 Geo/Hydro Impact 1 – Altered Recharge and Drainage Regime

Specific Adverse Environmental Impact. The Applicant proposes to direct all surface water discharge to a central pond or ponds (see Section 4.4.2, Measure b). This would shift aquifer recharge from upper areas to lower elevations, potentially affecting groundwater levels upslope of the pond(s). In addition, by channeling all drainage to a single point, the pond(s) could overflow during heavy rains, thereby decreasing the amount of water available to recharge the aquifer.

4.4.3.2 Geo/Hydro Mitigation 1

Revise the mining plan by replacing the Applicant-proposed central pond with a multiple-point and upslope drainage plan to more closely mimic the existing infiltration pattern on the site. Specific elements of the revised drainage plan could include the following measures:

a. Construct standard benches proposed by the Applicant with a reverse slope back into the hill to encourage infiltration in the upper portions of the mine, rather than directing all water down to a single detention/infiltration pond.

b. Redirect infiltration to the relative elevation that generates the runoff. For example, runoff generated from the containment cells would be infiltrated at the higher native elevations of the site.

c. Install a series of temporary water collection ponds on upper slopes as part of each mining phase. Most areas under active mining would require no surface water detention or storage since water would readily enter the exposed sand and gravels, rather than washing over the surface and collecting in pools. However, where roads are present, where compaction has occurred, or near areas of stockpiled tills or other less permeable materials appropriate drainage and upslope infiltration ponds should be constructed.

d. Incorporate the numerical simulation model of the groundwater system beneath the site developed by the Department of Ecology (Pacific Groundwater Group 2000) into the final mine design. The simulations and all other available information would be used to plan the locations of infiltration facilities to mitigate the changes in the site infiltration characteristics. This model and mine plan would be revisited through periodic review to allow for changes based on the results of ongoing monitoring. Further numerical simulations could be developed to predict the amount of mounding that may occur and allow for the final mine floor to be determined based on the increased height of the static water level at the infiltration facilities.

e. During reclamation, allow water to infiltrate within the cell for each completed mining phase, rather than directing flow to the central portion of the site.

Regulatory/Policy Basis for Condition. The site is within a groundwater protection special district overlay. Per KCC 21A.38.150, such areas require special attention to protect groundwater quality and infiltration rates.

In addition, King County policy NE-303 states that:

Development should occur in a manner that supports continued ecological and hydrologic functioning of water resources. Development should not have a significant adverse impact on water quality or water quantity. On Vashon Island, development should maintain base flows, natural water level fluctuations, ground water recharge in Critical Aquifer Recharge Areas and fish and wildlife habitat.

4.4.3.3 Geo/Hydro Impact 2 – Greater Peaks and Lows in Water Table and Potential Intrusion into Groundwater

Specific Adverse Environmental Impact. Mining would eventually reduce the deep layer of sand and gravel deposits at the site. This would in turn reduce the time it takes water to reach the water table and would likely result in greater peaks and lows in groundwater levels throughout the year. If mining depths were based on pre-mining groundwater levels, then mining could intercept groundwater.

4.4.3.4 Geo/Hydro Mitigation 2

Require direct measurement of groundwater levels as mining approaches final grade. Additional exploration boring and monitoring wells could provide data to reduce the uncertainty of the zones of elevated moisture encountered in OBW-6 and OBW-7. If perched water is actually found that contributes to offsite locations, mine design plans could be modified. Additional explorations could be required throughout the life of the mine to verify static water levels within mine phases to assure that the minimum 15-foot buffer is maintained. A minimum 25-foot separation between mining and the existing groundwater level could be required until documented and approved by King County that final grades would not be within 15 feet of maximum groundwater levels. Adjustments of final elevations should be made to accommodate potential increases in groundwater levels.

The infiltration facilities should be concentrated along the toe of the western mine walls as far from saltwater as possible.

Note that the alternative drainage concept presented as Geo/Hydro Mitigation 1 would also serve to mitigate this impact.

Regulatory/Policy Basis for Condition. Same as Geo/Hydro Impact 1: KCC 21A.38.150 and KC policy NE-303.

4.4.3.5 Geo/Hydro Impact 3. Increased Water Use

Specific Adverse Environmental Impact. During dry periods, the Applicant proposes to use up to 10,000 gallons of water per day to control dust. Therefore, at maximum, use, the project would increase water consumption on Vashon/Maury Island by 0.8 percent above present average levels. If water from on-island sources were used, this could affect the availability of water on the island.

4.4.3.6 Geo/Hydro Mitigation 3

Water conservation measures and consumption monitoring and reporting would allow for long-term avoidance of impacting local water supply. Such conservation measures should be specified in a water conservation plan to be prepared and approved by King County as a condition of permit approval.

The Applicant could use the existing Water Right Claim to obtain water for dust control or bring water from an off-island site, if approved by King County. Since the proposed mining activity at the site would increase recharge through the life of the active mining, this water use would be offset by additional recharge. Moreover, any water applied that did not evaporate would contribute to aquifer recharge.

Alternatives to using the local water supply could be implemented if monitoring identifies a potential impact.

Regulatory/Policy Basis for Condition. Same as Geo/Hydro Impact 1: KCC 21A.38.150 and King County policy NE-303.

4.4.3.7 Geo/Hydro Impact 4: Potential Fuel or Other Spill

Specific Adverse Environmental Impact. Equipment and vehicles operating on the site would require periodic refueling and maintenance. There is a potential for spillage of fuels and of various lubricating and hydraulic oils and fluids used in maintenance, which could contaminate soil or groundwater.

4.4.3.8 Geo/Hydro Mitigation 4

A designated fueling area could be established to contain possible fuel spills. The area could be lined with fabric under gravel, could be constructed of concrete with appropriate spill capture reservoirs, or could involve the placement of absorbent pads. Such measures would effectively eliminate significant risks to groundwater contamination from fuels.

Regulatory/Policy Basis for Condition. Washington State laws as stated in 90.48 RCW, the Water Pollution Control Act and chapter 90.54 RCW the Water Resources Act of 1971, and as implemented in Chapter 173-200 WAC, Water Quality Standards for Groundwaters of the State of Washington. These laws and regulations regulate the requirement to maintain the groundwaters of the state in their existing condition.

4.4.3.9 Geo/Hydro Impact 5

Specific Adverse Environmental Impact. Mining would alter the existing topography at the site and remove surface material, which could lead to potential slope stability problems. In addition, construction of the containment berm on the upper slope at the north end of the property would add weight to the top of the slope.

4.4.3.10 Geo/Hydro Mitigation 5

a. Perform slope stability calculations to assure that the final mine slopes would be stable. These slope stability calculations would include the effects of the containment cell proposed to be constructed along the top of the mine slopes. The calculation of slope stability for constructed slopes such as proposed for this site is a common requirement for projects of this magnitude.

b. During design, select final placement of containment cells such that the extra weight of material placed would not affect slope stability.

Regulatory/Policy Basis for Condition. Slope control is technically and economically feasible and is, in fact, required under the state Surface Mining Act. King County Code (KCC) Section 16.82.100 gives several operational conditions and standards of performance that address concerns regarding slope stability, and Section 16.82.40 provides specific authority to require elimination of hazards, including slope hazards.

4.5 Cumulative Impacts

Since the project would not affect aquifer recharge or water quality, no cumulative impacts would occur in these areas. Use of water for dust control would be an additive water use on the Island if the Applicant did not use the existing onsite water right claim.

4.6 Significant Unavoidable Adverse Impacts

No significant impacts that cannot be mitigated are likely.

Groundwater intrusion could be avoided through known standard mining practices so that contamination and/or aquifer breech would be highly unlikely.

No evidence exists that the project would reduce aquifer recharge. Rather, aquifer recharge would temporarily increase during active mining. The project would allow nearly the entire site to remain pervious to water infiltration. In addition, about 75 percent of the site would remain vegetated at any one time, which is nearly twice that required under KCC 21A.38.150, groundwater protection special district overlay.

Aquifer protection measures similar to those presented in this FEIS are not technically difficult and have been applied successfully at other mining projects throughout the western United States. Therefore, there is no reason to believe that such measures would not work at the Maury Island site.

Long-term monitoring and adaptation of the mining plan, as is typical and as would occur with this project, would ensure significant impacts on water resources are avoided.

4.7 Citations

AESI. See "Associated Earth Sciences, Inc."

Associated Earth Sciences. 1998. Soils, geology, geologic hazards and groundwater report, existing conditions, impacts and mitigations, Maury Island pit. Prepared for Lone Star Northwest, March 27, 1998, revised April 27, 1998.

______. 1999. Draft addendum geology and groundwater report. Maury Island pit, King County, Washington. March 3. Prepared for Lone Star Northwest, Inc.

Booth, D.B. 1991. Geologic map of Vashon and Maury Island, King County, Washington, with text to accompany map MF2161. U.S. Department of the Interior, U.S. Geological Survey, Map Distribution Center. Denver, CO.

Carr and Associates. 1983. Vashon/Maury Island water resources study. December 1. Prepared for King County Department of Planning and Community Development.

Driscoll, Fletcher G. 1986. Groundwater and wells. Johnson Filtration Systems.

Ecology. See "Washington State Department of Ecology".

ESM. 1998. Reclamation Permit for Lone Star Northwest's Maury Island's sand and gravel pit. Prepared for Lone Star Northwest. November 1996. Revised January 1997. Second revision April 1998.

King County. 1998. King County surface water design manual. King County Department of Natural Resources. September.

Pacific Groundwater Group. 2000. Maury Island gravel mine hydrolgeologic impact assessment. May. (Ecology Publication Number 00-10-026.) Seattle, WA. Prepared for Washington State Department of Ecology, Northwest Regional Office, Bellevue, WA.

Ritzi, Robert 1983. The hydrologic setting and water resources of Vashon and Maury Islands, King County Washington. Thesis of Master of Science fulfillment, Wright State University, June 1983.

Vashon-Maury Island Ground Water Advisory Committee. 1998. Vashon-Maury Island groundwater management plan and supplement, area characterization. King County Department of Natural Resources.

Washington State Department of Ecology. 2000a. Maury Island gravel mining impact studies. Mid-study fact sheet. January. Washington State Department of Ecology. Olympia, WA.

______. 2000b. Maury Island gravel mining impact studies. Final fact sheet. July. Washington State Department of Ecology. Olympia, WA.

______. 2000c. Water rights application tracking system for all of Maury Island. Printed February 9, 2000

______. Central Files. Well logs for sections 20, 21, 22, 28, 29, 30, 31, and 32 Township 22N, Range 3E.